

## MEASUREMENT OF PARTICLE TEMPERATURES DURING COAL PYROLYSIS AND COMBUSTION

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### Introduction

The surface temperature of pyrolyzing and/or burning coal particles has been the subject of intensive investigation (1-6) because it is important in the estimation of the rate of devolatilization and/or carbon oxidation. A number of models have been established in order to predict the surface temperature of pulverized coal particles smaller than 200  $\mu\text{m}$  diameter. However, few convincing models for millimeter size coal particles have emerged because of the complication of temperature gradients within the particle.

The ignition mechanism of coal particles in a hot oxidizing atmosphere is another subject of debate (5-8). Further experimental work is needed to determine whether initial ignition occurs homogeneously in the gas phase or heterogeneously at the particle surface.

The work presented here had three objectives: firstly, to develop a technique to monitor the transient temperature variations in the gas phase around a single particle during pyrolysis and/or combustion; secondly, to extrapolate the data to estimate the particle surface temperature; and thirdly, to analyze the ignition mechanism of coal and char particles.

### Experimental Equipment

A schematic diagram of the equipment is shown in Figure 1. For pyrolysis studies, a flow of prepurified nitrogen was passed over copper at 673 K to remove oxygen, then through a drierite column to remove water. Dry air was used to study combustion. The reactor, a horizontal vycor tube of 8 mm internal diameter, is heated by two enclosing furnaces. The first furnace acts to preheat the in-coming gas while the second maintains the reactor at the desired temperature.

Details of the sample injection and temperature measurement systems are given in Figure 2. A single coal particle was introduced by gravity through an electromagnetically controlled injector. An electrotrigger was used to energize a 24 volt (DC) solenoid which injects the particle into the reactor.

A new approach was used to measure the transient temperature variations around the coal particle. A group of extra-fine Chromel-Alumel thermocouples with 0.05 mm diameter was employed to provide precise temperature measurement with rapid response. The thermocouples were protected by two-hole ceramic tubes. Four thermocouples were bound together using high temperature cement to form a thermocouple array (Figure 2). In order to simplify the calculation of the temperature gradient, the distance between adjacent thermocouples in the array was always the same. In this study, 0.5 and 1.0 mm spacings were used. The voltage signals generated by the thermocouple array were amplified then converted into digital signals in the data acquisition system before being sent to the microcomputer. When the particle injector was triggered, the computer was

automatically initialized to record the output of the thermocouples at 2 millisecond intervals and the data stored on disk for later analysis.

### Procedure

The characteristics of the Texas subbituminous coal used are shown in Table 1. For each run a 1 mm diameter coal particle was injected into the reactor containing either preheated nitrogen or air. The bulk gas temperature was held constant at 873 K for all the experiments reported here. Before particle injection, the gas flow was stopped so that the experiments were carried out essentially in a static system. Char particles were prepared by injecting coal particles into the reactor swept by nitrogen at 873 K for 30 minutes.

### Results and Discussion

The temperatures measured by the thermocouple array as a function of time, and the extrapolated surface temperatures of the single coal and char particles, are presented in Figures 3, 4 and 5 for coal pyrolysis, coal combustion and char combustion, respectively. A pyrolysis run illustrated by Figure 3 shows the temperature variations caused by the transient heat transfer between the hot gas environment and the colder coal particle. The temperature profiles illustrate the practical thermal boundary layer in the vicinity of a pyrolyzing coal particle. A rapid drop followed by a rapid increase in temperature occurred in the spherical layer 1 mm away from the particle surface while almost no temperature variation was detected 4 mm away from the particle surface.

Data for the combustion of coal and char particles are shown in Figures 4 and 5, respectively. A significant aspect of coal combustion in Figure 4 is the sudden temperature rise in the gas phase about 1.5 mm from the surface of the coal particle, compared with the much smoother curve for char combustion shown in Figure 5. Point A in Figure 4 is significant because it represents a transition from net heat loss to net heat gain by the gas. The gaseous layer surrounding the particle experienced a rapid temperature drop prior to point A and a rapid increase after this point, in contrast with the relatively smooth increase in the particle surface temperature. This implies that homogeneous ignition occurred in gas phase rather than heterogeneous ignition at the particle surface. For the experimental conditions used, the homogeneous ignition temperature was around 830 K with approximately 800 ms induction time, as represented by point A in Figure 4. This is in general agreement with the calculated results of Annamalai and Durbetaki (5). The temperature in the homogeneous combustion layer increased rapidly as the volatile matter was combusted until there was not sufficient volatile matter evolving from the particle to sustain homogeneous combustion (point B in Figure 4). The remaining and subsequently-evolved volatile matter then experienced slower oxidation with a lower heat release rate. Consequently, there was a drop in the temperature in the surrounding gas layer. Because of the need to exceed both the ignition temperature and volatile matter concentration, homogeneous combustion was observed only in the thin spherical layer about 1.5 mm from the particle surface. No rapid gas temperature rise was detected by the thermocouples closer to, or farther from, the particle surface.

Particle surface temperature and heating rate versus time are given in Figures 6 and 7, respectively. The heating rate is of interest because it is related to the rate of devolatilization and char combustion. The significance of devolatilization on combustion is seen clearly in Figures 6 and 7 which indicate that during pyrolysis the coal particle heating rate was slow and the particle temperature never exceeded the reactor temperature. In the case of devolatilized char particles a higher heating rate was observed up to the equilibrium burning

temperature of 1075 K, about 200 K higher than the reactor temperature. Figure 7 shows that coal particles had the same heating rate initially during pyrolysis and combustion until divergence at point C. This point corresponds to that of homogeneous ignition in Figure 4. After point C the heating rate was higher for combustion than pyrolysis because the heat from the homogeneous combustion reactions was transferred to the particle surface.

Two major differences existed between the char and coal during combustion. Firstly, no temperature rise in the gas was detected at any distance from the char surface (Figure 5). Secondly, the surface temperature of the char particle increased at a higher rate than that of the coal particle (Figure 6). This supports the concept of heterogeneous ignition of the char particles.

#### Conclusions

A fast response thermocouple array was employed to provide information on the transient heating processes associated with pyrolysis and combustion of 1 mm diameter coal and char particles at a furnace temperature of 873 K. The measured temperature variations implied that ignition occurred at the surface of the char particles but in the gas phase surrounding pyrolyzing coal particles. Homogeneous ignition occurred at 830 K causing a temperature rise in the gas in a narrow spherical layer about 1.5 mm from the surface of the coal particle.

#### Acknowledgements

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#### References

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**Table 1**  
**Characteristics of Texas Subbituminous B Coal,**  
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| <u>Proximate Analysis (wt%)</u>           | <u>As Received</u> | <u>Dry Basis</u> |
|---|--------------------|------------------|
| Moisture                                  | 24.11              |                  |
| Ash                                       | 10.31              | 13.59            |
| Volatile Matter                           | 38.31              | 54.48            |
| Fixed Carbon                              | 27.27              | 35.93            |
| <u>Ultimate Analysis (wt%)</u>            |                    |                  |
| C   | 47.58              | 62.69            |
| H   | 4.01               | 5.29             |
| N   | 0.71               | 0.93             |
| S (total)                                 | 1.34               | 1.76             |
| O (diff.)                                 | 11.95              | 15.74            |
| Calorific Value Btu/lb<br>(mm-Free Basis) | 9836               | 13540            |

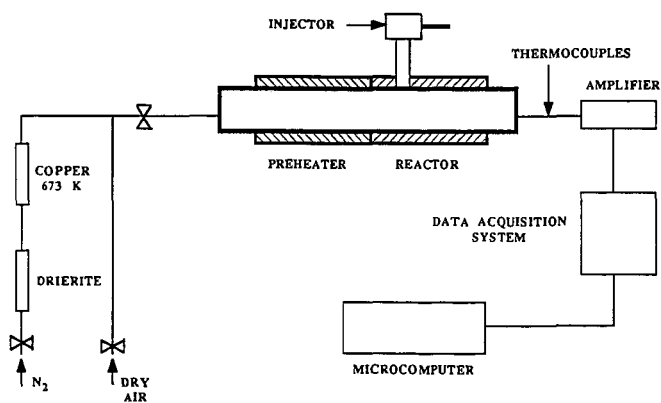


FIG. 1 SCHEMATIC DIAGRAM OF THE EQUIPMENT

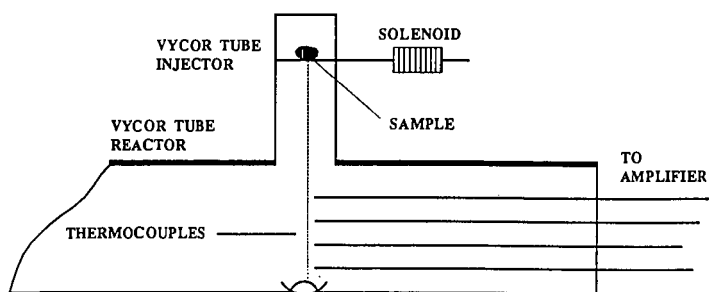


FIG. 2 INJECTION AND TEMPERATURE MEASUREMENT SYSTEM

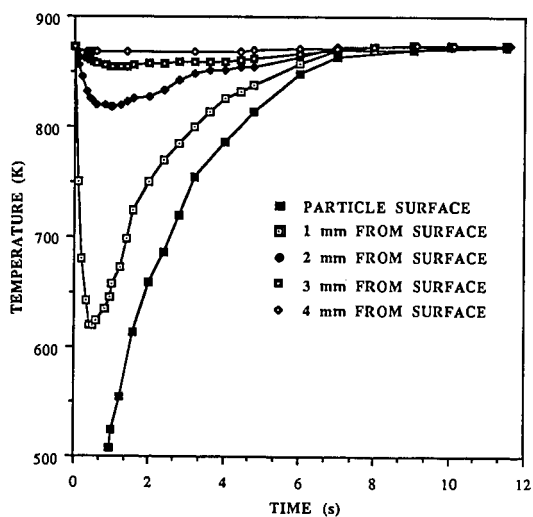


FIG. 3 TEMPERATURE HISTORY OF COAL PARTICLE SURFACE DURING PYROLYSIS

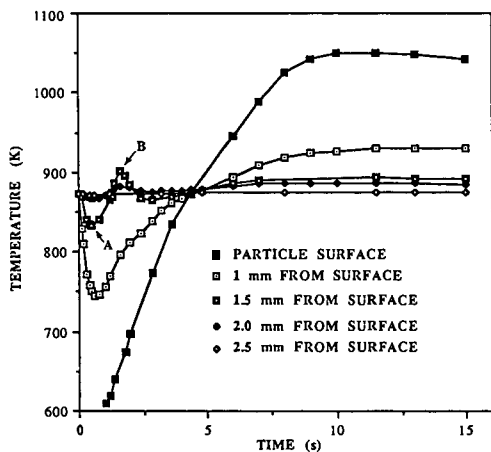


FIG. 4 TEMPERATURE HISTORY OF COAL PARTICLE SURFACE DURING COMBUSTION

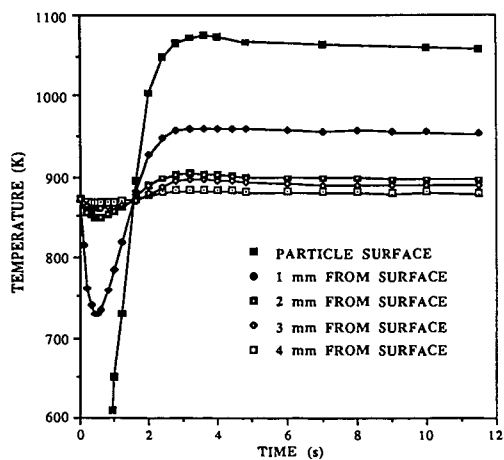


FIG. 5 TEMPERATURE HISTORY OF CHAR PARTICLE SURFACE DURING COMBUSTION

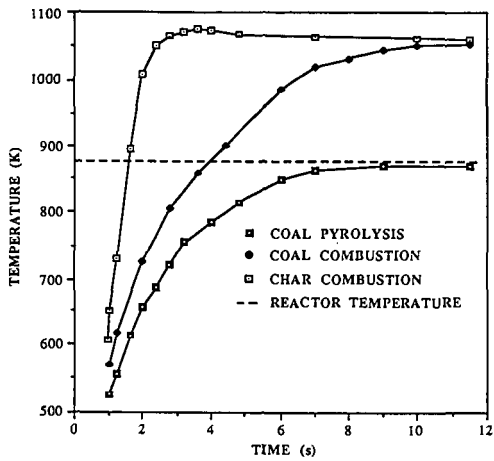


FIG. 6 TEMPERATURE HISTORY OF THE PARTICLE SURFACE

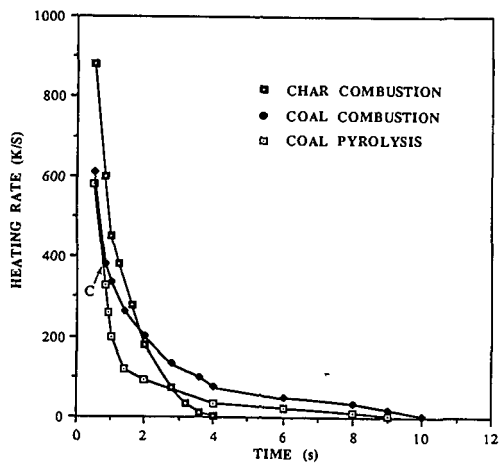


FIG. 7 HEATING RATE VERSUS TIME